AD-A043 695 LOUISIANA STATE UNIV BATON ROUGE COASTAL STUDIES INST F/G 8/3

WAVE ACTION AND SEDIMENT TRANSPORT ON FRINGING REEF.(U)

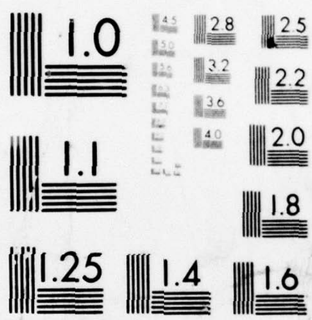
DEC 77 J N SUHAYDA, H H ROBERTS N00014-75-C-0192

UNCLASSIFIED TR-239 NL

| OF |

AD
A043 695

END
DATE
FILMED
9-77
DDC




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Coastal Studies Institute
Center for Wetland Resources
Louisiana State University
Baton Rouge, Louisiana 70803



9 Technical Report No. 239

6 WAVE ACTION AND SEDIMENT TRANSPORT ON FRINGING REEF.

10 Joseph N. Suhayda and Harry H. Roberts

11 December 1977

12 9p.



14 TR-239



Reprint from
Proceedings, 3rd International
Coral Reef Symp., University
of Miami, May 1977, pp. 65-70.

15 Office of Naval Research
N00014-75-C-0192
Project No. NR 388 002

Proceedings, Third International Coral Reef Symposium
Rosenstiel School of Marine and Atmospheric Science
University of Miami
Miami, Florida 33149, U.S.A.
May 1977

# WAVE ACTION AND SEDIMENT TRANSPORT ON FRINGING REEFS

Joseph N. Suhayda and Harry H. Roberts
Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana 70803

## ABSTRACT

Measurements of wave processes, wave-driven currents, and sediment distribution have been made in several fringing reef systems. Wave height and wave period are typically reduced by about 50% as waves pass over the reef crest. This decrease depends primarily upon reef crest water depth, so that wave conditions in the back-reef lagoon show significant changes over a single tide cycle. Wave-driven currents tend to flow continuously onshore over the reef crest. Their velocity is greatest near low tide, when wave breaking is most intense. Current in the lagoon moat generally showed a tendency to drain the lagoon except during brief intervals near flooding tide when a weak current reversal occurred. Sediment distribution in the lagoon displays a pattern that reflects current patterns in the lagoon and wave characteristics at the lagoon shoreline.



**KEY WORDS:** Waves, Fringing Reef, Wave-Driven Currents, Sediment Dispersal Patterns

# WAVE ACTION AND SEDIMENT TRANSPORT ON FRINGING REEFS

Joseph N. Suhayda and Harry H. Roberts
Coastal Studies Institute, Louisiana State University
Baton Rouge, Louisiana 70803

## Introduction

Recent investigations (1), (2), (3) continue to demonstrate the importance of waves and wave-driven currents to coral reef ecosystems. These studies have indicated that several effects result from wave action, including the direct physical force on coral branches and the movement of water and sediment within the reef system. There are, however, problems with making accurate field measurements of wave action and with relating these measurements to coral growth (or destruction). The variability of reef geometries worldwide implies that many studies will be required even to assess wave characteristics on reefs. A detailed quantitative understanding of wave processes occurring on reefs will develop only after acquisition of these field data. This study presents the results of direct measurements of waves and wave-driven currents in natural reef systems. The measurements were limited to fringing reefs where a well-developed shallow lagoon was present shoreward of the reef crest. Although this system is somewhat specialized, it does contain many of the features and processes occurring on reefs in general.

Few field measurements of wave action on reefs have been reported in the literature, even though studies relating to wave action have been numerous. During the late 1940s and early 1950s Munk and Sargent (4) and von Arx (5) initiated indirect investigations of wave processes on reefs. Several studies followed, including investigations of wave refraction and wave energy on small coral islands of the Campeche Bank (6); of the swell on the island of Aruba (7); of the relationship between wave power and island landforms on the Windward Caribbean Islands (8); of the correlation of reef variability and wave action on Grand Cayman (3); and of the theoretical description of wave-induced set-up of water on coral reefs (9). Direct measurements of wave thrust on reefs have been reported (10), (11), and wave measurements on a fore-reef shelf have been made on Grand Cayman (12).

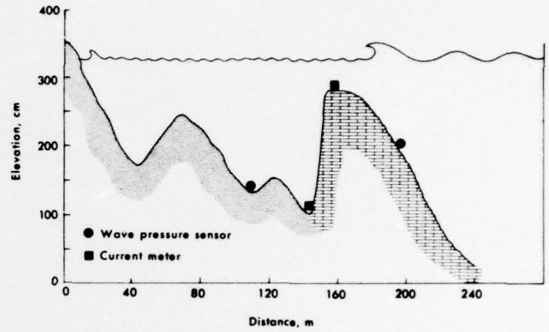



Figure 1. Profile view of reef and lagoon system on Great Corn Island, Nicaragua, and the location of wave and current instruments.

## Wave Processes

A typical example of the type of reef system in which the wave measurements were made is shown in Figure 1. The reef is located on the northern coast of Great Corn Island, Nicaragua. The reef system includes a fringing reef barrier that slopes gently seaward and a steep landward-facing scarp. The reef encloses a lagoon having a sediment-covered floor and a well-developed moat immediately behind the reef. This segment of the fringing reef extends approximately 300 m along shore to a point where inlet channels occur and separate this reef from other extensions of the reef system. Waves typically break on the reef crest and continue breaking until they reach the moat. At the moat the breakers reform into nonbreaking waves and propagate shoreward with a height and period that are lower than offshore wave conditions. Wave-driven currents sweep across the reef crest, and the landward-facing scarp is formed by large (∿0.5 m) pieces of coral rubble transported from the reef crest. Field sites having essentially the same reef crest and lagoon characteristics were studied on Grand Cayman, B.W.I.; Barbados, W.I.; and the northeastern coast of Brazil.

The shallow fringing reef crest is a critical zone for wave processes on reefs because

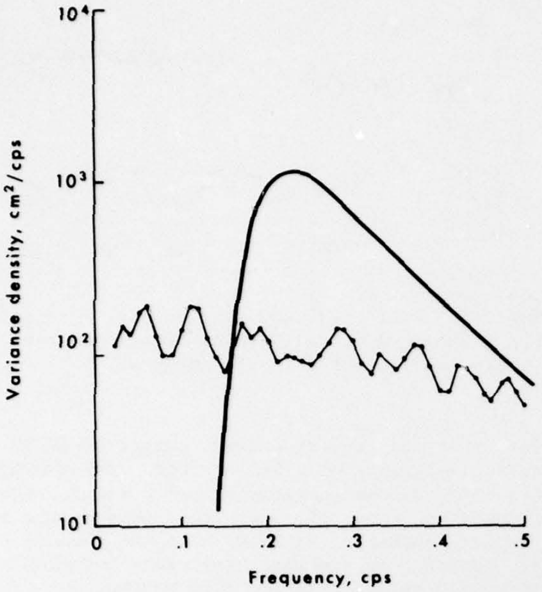



Figure 2. Wave spectra from a measurement inside the reef crest (dotted line) compared to Pierson-Moscowitz input spectrum (solid line) inferred from 6 m/sec trade wind, illustrating the extreme modification due to wave breaking [after (13)].

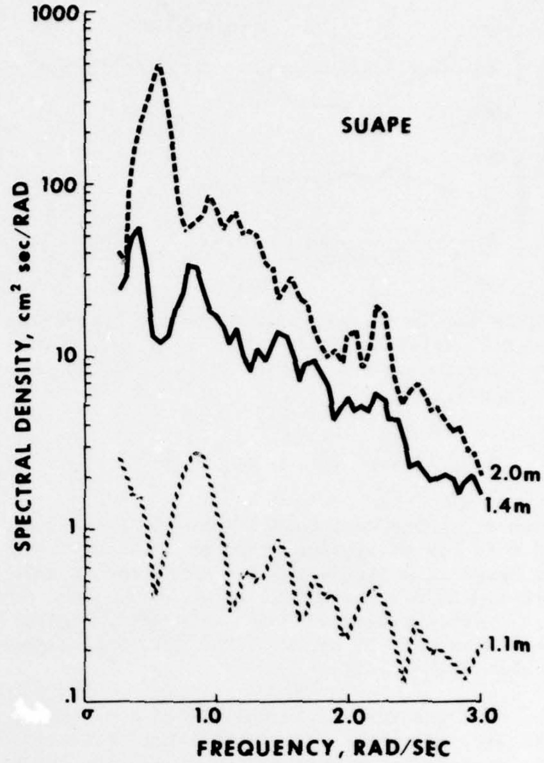



Figure 3. Measured wave spectra in the Suape Lagoon at different stages of the tide.

interactions there cause extreme modification of the incoming waves. The main feature of the reef crest affecting the waves is its shallow depth, typically 1 m, which normally causes wave breaking. Tide, of course, causes the actual depth to vary throughout the day. Waves may break continually as they transect the reef crest until reaching the deeper lagoon water, or they may propagate unbroken until secondary wave crests are formed. Observations at the point of reformation, taken in a fringing-reef-formed windward lagoon on Barbados, are shown in Figure 2. For comparison, the deepwater Pierson-Moscowitz (PM) spectrum for a typical trade wind speed [6 m/sec (13)] is also shown because no actual measurements were made on the fore-reef shelf. Two features are obvious: there has been a substantial loss of wave energy, and the wave spectrum has significantly changed shape. The estimated energy loss, calculated from the change in wave height, for the observed conditions is about 75%. This result is in rough agreement with laboratory measurements of wave transformation over a submerged shoal (14). This energy loss has not been uniform because the observed spectrum shows that considerable energy remains at low frequencies. Thus breaking has flattened the spectrum peak and perhaps transferred energy to low frequency. The exact amount of energy loss and the spectral change induced depend upon the depth of water over the reef crest and the input wave conditions. The reef crest did not contain surge channels, which have been observed in Pacific reefs (4) to significantly modify the incoming waves.

Measurements of waves near the shoreline at Suape, Pernambuco, Brazil, behind a beach rock barrier are summarized as wave spectra and are shown in Figure 3. Geomorphically, the beach rock barrier has the same basic components as most well-developed fringing coral reef systems: a seaward-sloping barrier, back-barrier moat, back-barrier lagoon, and occasional breaks in the barrier trend (inlets). The measurements shown are for three tide stages and show the effect of water level changes at the reef crest. At a tide datum of 1.1 m the water level was at the crest of the barrier. Wave height was 7 cm and the spectrum showed several peaks. At a tide level of 1.4 m the wave height had increased to 28 cm, and the height at a tide level of 2.0 m had increased to 56 cm. The offshore wave height was about 1 m.

The process of wave breaking is, at present, not well described by hydrodynamic theory. The decrease in wave height across a reef crest resulting from breaking can, however, be given empirically. Using the data of this study and published data (14), wave height at the point of reforming H is given by

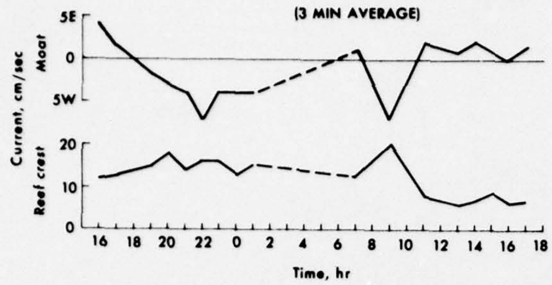



Figure 4. Twenty-six-hour record of current on the reef crest and in the back-reef moat. Current magnitudes are average values over 3 min of record.

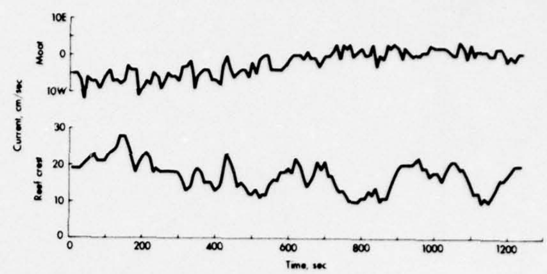



Figure 5. Reef crest and moat current records over a 20-min period. Current magnitudes are average values over a 10-sec interval.

$$H = H_o\ (1 - 0.8e^{-0.6\ d/H_o})$$

where $H_o$ is the wave height near the breakpoint and d is the mean water depth at the reef crest. The range of water depths for which the formula is valid is $d/H_o$ from zero to about 5. This formula indicates that when $d/H_o = 0$ wave heights in the lagoon will be about 20% of the wave heights outside the reef.

Wave periods within the lagoon are highly variable, and the spectrum indicates that several wave periods occur with nearly equal wave height. Generally, the mean wave period in the lagoon is smaller by about 50% to 75% than the wave period offshore.

## Wave-Driven Currents

Waves that break on the reef crest drive water shoreward into the lagoon. This shoreward flow provides the mechanism for transporting water and sediment from the fore-reef shelf environment into the back-reef lagoon. Water brought across the reef crest has been shown to exit the lagoon through channels in the fringing reef (15), (16). Previous studies have suggested that tidal currents may reverse the direction of flow of water on the reef crest and in the reef channels. Current measurements were made at two locations on Great Corn Island to document the characteristics of reef crest and moat currents (Fig. 1).

The reef crest current meter was oriented in an onshore-offshore direction, and the moat current meter was aligned parallel to the alongshore dimension of the reef. The position of the moat current meter was near a break in the reef crest and probably reflects flow in the inlet channel.

Figure 4 shows current observations on the reef crest and in the moat over a 26-hour period. Data represent average current over a 3-min section of record. Actual instantaneous measurements show the effect of each wave transiting the reef crest and causing current surges of 50-80 cm/sec for durations of a few seconds. The average data indicate that, although moat currents reverse direction of flow, the reef crest current was continuously onshore. At 1600, with the tide falling, currents on the reef crest were moderately strong (10 cm/sec) and the flow in the moat was changing from east (or filling the lagoon) to strongly westward (draining the lagoon). Near low tide (0000), the reef crest current reached a maximum and currents in the moat reach a maximum. As the tide rose, the westward flow in the moat was reversed to eastward and reef crest currents generally decreased. Near high tide (~1200) reef currents are minimal and the current in the lagoon is eastward. This change in reef crest current flow results from the fact that at low tide wave breaking is more complete on the reef crest and more of the wave energy goes to driving the current over the crest and into the back-reef lagoon.

Figure 5 shows a sample of the averaged reef crest and moat current values over a 20-min period (1200 sec). At this time scale more detail of the time changes in the record is noticeable. The data show the importance of variations in speed at a period of about 100-150 sec on the reef crest. These variations may be related to long-period gravity waves generated on the reef face by the breaking waves and/or the effect of groups of high waves. The data indicate that variations about the mean speed of up to 50% can occur within 1 or 2 min. The moat current record shows no corresponding variations at 100-200 sec period; however, variations at approximately a 50-sec period do occur.

## Sediment Movement

It has been suggested that circulation of water and sediment distribution within a fringing reef lagoon are determined by lagoon geometry and the input of water across the reef crest (15), (16). The inflow of water may be wave or tide induced, although wave input has been reported to dominate (5), (11). Wave-induced input results from wave breaking and set-up on the reef crest.

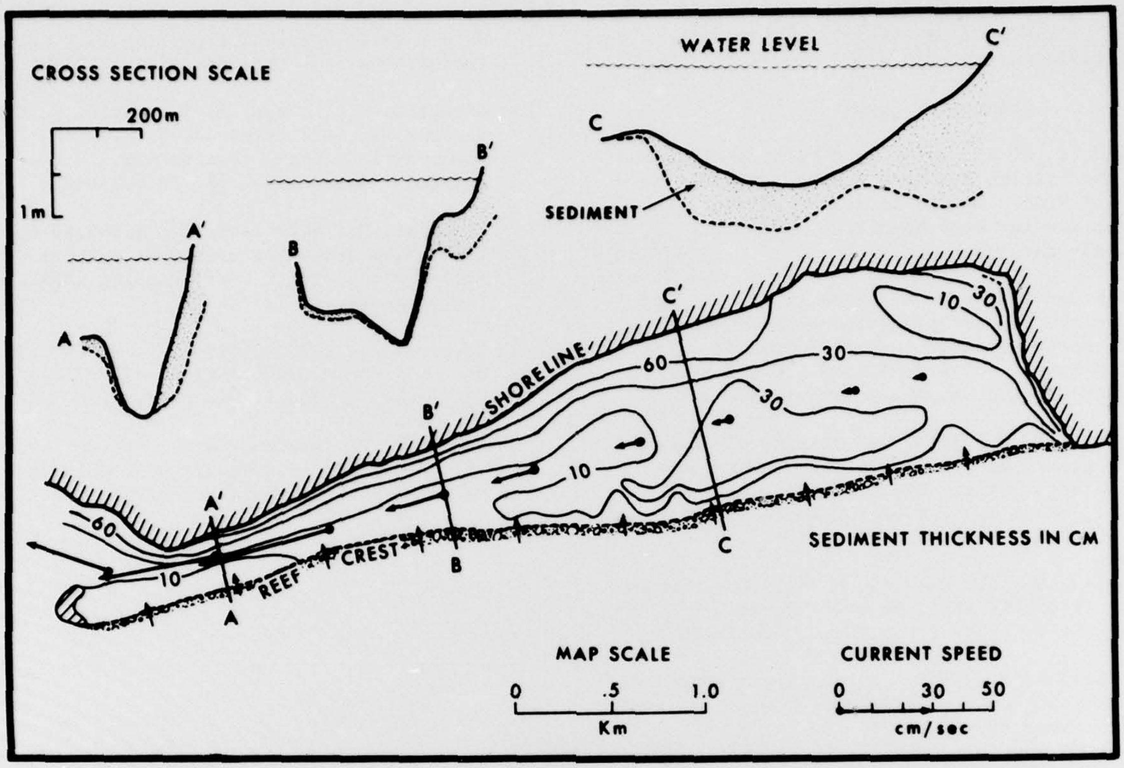



Figure 6. Sediment thickness distribution in South Sound shown in plan view and cross section, and the lagoon axis current speed (shown by arrows). Note the correspondence of the thick sediment accumulations and low speed, and thin sediment accumulation and high speed [after (12)].

which are enhanced as water depth on the reef crest decreases. Using the wave data taken during the Cayman experiment (12), the influx of water across the reef crest at South Sound, Grand Cayman, can be calculated. Conservation of this water flux allows the average transport within South Sound to be calculated as a function of position down the axis of the lagoon. As a result of the geometry of South Sound (Fig. 6), the influx of water over the reef crest is funneled to the west. Currents in the lagoon calculated for an input current across the reef crest of 10 cm/sec are shown in Figure 6. Lagoon current speeds range from 2 to 45 cm/sec, being lowest in the eastern part. Examination of sediment thickness within the lagoon (Fig. 6), as determined by probe stations in a gridded array, indicates a distribution in accordance with the current field. Thick, fine-grained sediment accumulations occur in the eastern part of the lagoon (see section C-C'), and as the lagoon narrows and currents increase sediments become coarser and thickness decreases abruptly (section A-A', B-B'). Thick accumulations of relatively coarse sediments occur along the island coast as a result of beach building by wave action in the lagoon. For the given volume flux of water (400 $m^3$/sec) over the reef crest, the lagoon volume (3.3 x $10^6 m^3$) could be replaced in about 2.5 hours; the implication is rapid renewal of lagoon water. Thus it appears that sediment distribution and nearshore wave and current fields are linked in a system to reef crest and lagoonal morphology.

## Conclusions

Measurements of waves and wave-driven currents at several field sites indicate that wave processes at the reef crest are intense and important to the movement of water and sediment in a fringing reef system. Wave height is reduced by breaking to a fraction (i.e., 40%) of input wave height. Wave breaking drives currents across the reef crest into the back-reef lagoon, and these currents appear to control circulation and sediment dispersal in the lagoon. Tidal variations in water level on the reef crest cause diurnal variations in both lagoon wave heights and wave-driven currents.

## Acknowledgments

The research presented in this paper was supported by the Geography Programs, Office of Naval Research, Arlington, Virginia 22217, under a contract with the Coastal Studies Institute,

Louisiana State University. Appreciation is extended to the many individuals who made the foreign field work possible and successful.


References Cited

(1) Stoddart, D. R., 1973, Port-hurricane changes on the British Honduras reefs; re-survey of 1972. Proc., Second Inter. Coral Reef Symp., Great Barrier Reef Committee, Brisbane, p. 473-483.

(2) Hernandez-Avila, M. L., Roberts, H. H., and Rouse, L. J., 1977, Hurricane-generated waves and coastal boulder rampart formation. Proc., Third Inter. Coral Reef Symp., Great Barrier Reef Committee, Miami, in press this volume.

(3) Roberts, H. H., 1974, Variability of reefs with regard to changes in wave power around an island. Proc., Second Inter. Coral Reef Symp., Great Barrier Reef Committee, Brisbane, p. 497-512.

(4) Munk, W. H., and Sargent, M. S., 1954, Adjustment of Bikini Atoll to ocean waves. U.S. Geol. Surv. Prof. Paper 260-C, p. 275-280.

(5) von Arx, W. S., 1954, Circulation systems of Bikini and Rongelap lagoons. U.S. Geol. Surv. Prof. Paper 260-B, p. 265-273.

(6) Walsh, D. E., Reid, R. O., and Bader, R. G., 1962, Wave refraction and wave energy on Cayo Arenas, Campeche Bank. Texas A & M Res. Foundation Project 286(a), p. 1-62.

(7) Wilson, W. S., Wilson, D. G., and Michael, J. A., 1973, Analysis of swell near the island of Aruba. J. Geophys. Res. 78, p. 7834-7844.

(8) Hernandez, M. L., and Roberts, H. H., 1974, Form-process relationships on island coasts. Tech. Rept. 166, Coastal Studies Inst., Louisiana State Univ., 76 pp.

(9) Tait, R. J., 1972, Wave set-up on coral reefs. J. Geophys. Res. 77, p. 2207-2211.

(10) Shinn, E. A., 1963, Formation of spurs and grooves on the Florida reef tract. J. Sediment. Petrol. 33, p. 291-303.

(11) Storr, J. F., 1964, Ecology and oceanography of the coral-reef tract, Abaco Island, Bahamas. Geol. Soc. Amer. Special Paper 79, p. 1-98.

(12) Roberts, H. H., Murray, S. P., and Suhayda, J. N., 1975, Physical processes in a fringing reef system. J. Mar. Res. 33, p. 233-260.

(13) Garstang, M., LaSeur, N. E., Warsh, K. L., Hadlock, R., and Peterson, T. R., 1970, Atmospheric-oceanic observations in the tropics. Amer. Sci. 58, p. 482-495.

(14) Nakamura, M., Shiraishi, H., and Sasaki, Y., 1966, Wave dampening effect of submerged dike. Proc., Tenth Conf. Coastal Engr., Tokyo, Japan, p. 254-267.

(15) Kohn, A. J., and Helfrich, P., 1957, Primary organic productivity of a Hawaiian coral reef. Limnol. Oceanogr. 2, p. 241-251.

(16) Inman, D. L., Gayman, W. R., and Cox, D. C., 1963, Littoral sedimentary processes on Kauai, a subtropical high island. Pacific Sci. 17, p. 106-130.

Unclassified
Security Classification

# DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana 70803

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
Unclassified

3. REPORT TITLE

WAVE ACTION AND SEDIMENT TRANSPORT ON FRINGING REEFS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Joseph N. Suhayda and Harry H. Roberts

6. REPORT DATE
December 1977

7a. TOTAL NO. OF PAGES
6

7b. NO. OF REFS
16

8a. CONTRACT OR GRANT NO.
N00014-75-C-0192

b. PROJECT NO.
NR 388 002

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Technical Report No. 239

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES
Reprint from: Proceedings, 3rd International Coral Reef Symp., University of Miami, May 1977, pp. 65-70.

12. SPONSORING MILITARY ACTIVITY
Geography Programs
Office of Naval Research
Arlington, Virginia 22217

13. ABSTRACT

Measurements of wave processes, wave-driven currents, and sediment distribution have been made in several fringing reef systems. Wave height and wave period are typically reduced by about 50% as waves pass over the reef crest. This decrease depends primarily upon reef crest water depth, so that wave conditions in the back-reef lagoon show significant changes over a single tide cycle. Wave-driven currents tend to flow continuously onshore over the reef crest. Their velocity is greatest near low tide, when wave breaking is most intense. Current in the lagoon moat generally showed a tendency to drain the lagoon except during brief intervals near flooding tide when a weak current reversal occurred. Sediment distribution in the lagoon displays a pattern that reflects current patterns in the lagoon and wave characteristics at the lagoon shoreline.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6811

Unclassified
Security Classification

A-31408

Unclassified
Security Classification

| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Waves<br>Fringing reefs<br>Wave-driven currents<br>Sediment dispersal patterns | | | | | | |

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

Unclassified
Security Classification

A-31409